**Derivation of Supply Curve of PV ~**

**Impact of Setback regulation ~**

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**Abstract**

abstract.

#용어정의: PV potential, solar potential, generation potential, capacity potential?

시나리오 이름을 Current Setback, No Setback으로 바꾸기

발전량을 기준으로 분석을 하는 이유는 발전량이 우리의 최종 목적이거니와 지역별 capacityfactor를 달리 적용하여, 그것이 의미가 있음.

Density factor와 Area factor를 적용함으로써 기존 연구들보다 현실적

**Keywords:** Keword1, Keword-2, Keyword-3

1. Introduction

As the 13th largest greenhouse gas (GHG) emitter, South Korea accounted for 1.3% of the global GHG emissions [1]. The country has pledged to achieve its nationally determined contribution (NDC) by 2030 and carbon neutrality by 2050 [2,3]. Like many nations, South Korea views the expansion of renewable energy as a key strategy for decarbonization. Globally, renewable energy represented 27.8% of the total electricity generation, whereas in South Korea, the share was significantly lower at 6.1% [4]. Even if the renewable energy generation share is lower than other countries, South Korea decided to lower the renewable energy target for 2030 from 30% to 22% [5]. The decision is based on the current government’s willingness to enlarge the role of nuclear power in the middle of energy transition.

In 2021, global renewable energy generation amounted to 7,857TWh, with hydro energy accounting for 4,400 TWh (56%), wind energy for 1,838 TWh (23%), solar energy for 1,033 TWh (13%), and other renewable sources contributing 586 TWh (8%). In terms of South Korea's renewable energy generation in 2022, the country produced a total of 50.4 TWh, distributed as follows: 30.7 TWh (61%) from solar energy, 11.9 TWh (24.0%) from bio energy, 3.4 TWh (7%) from wind energy, 3.5 TWh (7%) from hydro energy, and 0.8 TWh (1%) from other sources [6]. When comparing South Korea and the global status in terms of using renewable energy, there are significant differences in the types of renewable resources predominantly utilized. Globally, hydro energy is the largest contributor, making up 56% of total renewable generation. In contrast, South Korea heavily relies on solar energy, which accounts for 56.6% of its renewable energy production, far exceeding the global average of 13%. This highlights a stark contrast in renewable energy strategies, with South Korea placing a much greater emphasis on solar energy compared to the global status, where hydro and wind energy dominate.

According to the carbon neutrality scenario of South Korea, the renewable energy generation in 2050 is projected to be 889.9 TWh under ‘Scenario A’ and 736.0 TWh under ‘Scenario B’. Assuming the current share of solar energy in renewable energy generation (61%) remains constant, solar power generation in 2050 would amount to 542 TWh under ‘Scenario A’ and 449 TWh under ‘Scenario B’. Considering that the theoretical, technical, and economic PV potential of South Korea in 2020 was estimated to be 137,347 TWh/year, 3,117 TWh/year, and 495 TWh/year, respectively [7]. It indicates that the minimum required amount (449TWh) for carbon neutrality can likely be met when the economic potential (495TWh) is fully utilized. However, only 6% (30.7TWh) of the economic PV potential (495TWh) is currently being utilized.

There are several reasons for this underutilization of PV potential. The shapes of the renewable portfolio and energy mix are determined by many factors such as natural environment, energy security, economy, politics and others [8]. Energy policies could facilitate the expansion of renewable energy internalizing positive externalities from renewable energy [9,10]. On the other hand, some regulations could be barriers for promotion of renewable energy, even if the regulations have other purposes in the afraid of drastic and thoughtless expansion of renewable energy. In many countries environmental licensing is said to be a cause of delays in the completion of renewable energy farms [11–15]. In South Korea, setback regulation is controversial. Setback regulation means that PV facilities must maintain a minimum setback distance from designated sites (ex. residential areas, roads, parks, and cultural heritage) to be eligible for installation. As a result of opposition from local residents to installation of PV facilities, local governments are introducing the setback regulations [16]. Local residents oppose the installation of PV facilities due to concerns over environmental and visual impacts [17–20]. Even if efforts, for example sharing economic benefits from PV facilities [21–24], the participation of residents in the PV development process [25], increase of perceived trust of PV [26] and others, are being made to increase residents' acceptance of PV facilities, the opposition by residents is a major obstacle to the expansion of PV facilities. Especially in South Korea, setback regulations are detrimental due to i) the country's heavy reliance on PV and ii) the country's limited land area. As previously mentioned, 61% of South Korea's renewable energy generation comes from solar power. And South Korea ranks 22nd in population density among 216 countries worldwide, with 530 people living per square kilometer [27]. It is hard to find available sites that can meet all the necessary conditions for placing PV facilities. Therefore, it is important to examine the impact of setback regulations on PV potential in South Korea.

In previous studies, when setback regulations are applied nationwide, only 23% of the potential generation of PV can be utilized (566TWh out of 2,507TWh). In contrast, if these regulations were relaxed to 300 meters and 100 meters, the utilization rate of the potential would increase to 25% (625TWh) and 54% (1,365TWh), respectively [28]. In Incheon province, which faced the least setback regulations, only 68% of the potential site area was usable due to these restrictions. On the other hand, in Chungbuk and Chungnam, the regions most affected by setback regulations, only 22% of the potential site area could be utilized [29]. In three counties—Hampyeong in Jeollanam-do, Hamyang in Gyeongsangnam-do, and Gumi in Gyeongsangbuk-do—due to setback regulations, 54%, 53%, and 32% of the respective potential PV installation area are available [30]. This study aims to examine the impact of setback regulations on PV potential in Gyeonggi province, a province out of 17 ones in South Korea. Gyeonggi Province is composed of 31 cities (See supplementary for details in administrative). Out of the 31 cities, 12 have implemented setback regulations. These regulations mostly pertain to distances from residential areas and roads, with setback distances ranging from a minimum of 100 meters to a maximum of 500 meters (see Appendix for details).

Gyeonggi province accounts for 10.2 % of the country’s area [31] and 27% of its population [32]. It is the region where the introduction of renewable energy is most urgently needed among the 17 ones in South Korea [reference]. First, a regional differential electricity pricing system is currently being discussed in South Korea, and it is expected that a region's electricity self-sufficiency rate will determine retail electricity prices. Gyeonggi Self Sufficiency: 59% [33]. Therefore, Gyeonggi Province needs to increase its power supply to avoid economic losses caused by rising electricity prices. Second, South Korea has XX RE100 companies, and XX of them are headquartered in Gyeonggi Province [34,35]. Supplying these companies with locally produced renewable energy (e.g., through PPAs) will help them achieve their RE100 goals, preventing economic losses. Third, the governor of Gyeonggi Province is strongly committed to expanding solar power [36]. Despite the national renewable energy supply target being lowered in the 10th Basic Plan for Electricity Supply and Demand, the governor of Gyeonggi Province has declared a goal to install 9 GW of solar power during his term. In this context, the expansion of solar power in Gyeonggi Province is crucial.

Novelty를 mattsson et al. (2021)처럼 하는 건 어떨까

토지분류를 다양하게 했다는 장점,

Novelty of this paper

토지분류를 했다는 점.

setback영향을 경제적으로 파악했다는 점.

Geospatial supply curve (Sun et al. (2013)

#### Administrative Definition ####

Ko (2023) Rural opposition에서 아래 문구 인용.

Objective:

1) explore suitable sites for PV deployment. (GIS-based approach)

2) scenario analysis (No Setback vs. Setback)

3) Supply curve

Comparison of PV energy potential

4) Compare supply curve of PV (LCOE assumption)

4)

To what extent would solar generation be reduced by the setback regulation?

Which LandType should be focused on to increase solar potential?

Which cities should be focused on to increase solar potential?

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자동 생성된 설명

Fig. . Study design

1. Methodology
   1. GIS-based approaches

Land-use types are categorized.

* + 1. Geographical constraint

법적, 지형적 규제를 검토한 사항들에 대한 설명.

- (농지) 농업보호구역, 농업진흥지역

- (산지) 보전산지, 경사 15도.

- (전체) 이격거리

* 1. Calculation of PV potential

Annual (8,760 hours) theoretical potential generation ( in kWh) of PV in the given area ( in m2) would be calculated as the global horizontal irradiation ( in kW/m2) as followings.

The theoretical potential is limited to deliver meaningful information to policy makers. Geographical and technical constraints would be taken into account when we try to find more realistic estimation for the PV potential. The geographical and technical potential would be calculated as followings. [37–42]

Here, (in kWh/m2) is geographical and technical generation potential under geographical (ex. protected area) and technical constraints (ex. PV module efficiency). (unitless) is the packing factor, the ratio of the total PV array area to the land area PV arrays occupy. (unitless) is generator-to-system area ratio, which is the ratio of the area occupied by the PV generator (including PV arrays and the spaces between them) to the total suitable area available for the PV system. It indicates how efficiently the available area is utilized for placing PV systems. It measures how densely the PV arrays are packed within the occupied space. (unitless) is the performance ratio, the ratio of the actual generation achievable in practice to the ideal generation under no-losses conditions. Regardless of module efficiency and shading effect, it measures PV system losses from array temperature, surface soiling, panel degradation etc.[[2]](#footnote-3) is the module efficiency. is the shading factor.

In this study, instead, the reduced formula is applied as followings.

Here, (in kWh) is annual geographical and technical potential at an individual site (), located within a city& county (), classified as land-use type () and PV technology type (). (in m2) is the area of the individual site. (unitless) is the area factor, which represents the proportion of the area occupied by PV systems to the total area. It has the exact same meaning of in (eqn#). (in m2/kW) is the density factor, which represents the area required per 1kW of PV capacity. It indicates how densely PV systems are installed in a given area. (unitless) is the capacity factor of a PV system, defined by the ratio of the actual power generation to theoretical power generation if the PV system has generated at its maximum power output during same period [43,44]. The differences between the formula in the previous studies and the formula (# Eqn) in this study are i) measurement of PV installation size (PV module area in m2 vs. PV capacity in kW), and ii) measurement of PV system’s efficiency (disaggregation into performance ratio, module efficiency, and shading effect vs. capacity factor as integrated efficiency). In previous studies [sources], solar radiation that could be utilized by a PV system is measured, which is represented as in eqn#, while in this study, PV capacity that could be installed in the individual site is measured, which is represented as in eqn#. And in previous studies, energy losses associated with solar-to-electric power conversion, including shading losses are represented into three parts, which is represented as in eqn#, while in this study, the capacity factor, represented as in eqn#, the definition-based parameter, includes technical efficiency, shading effects, surface soiling etc.

* + 1. Total area

Data for the area of individual sites is obtained from GIS-based approach as previous section describes. XX% (XXm2) of the total Gyeonggi province area (XXm2) is explored which counts totally 100,000 individual sites.

* + 1. Area factor: total area to PV system area

Fig. 3 (c) shows the graphical concept of the area factor (). 100% of the total area cannot be utilized for PV system installation, since facilities that have nothing to do with PV operation or unsuitable terrain for placing PV systems in its shape and size or other reasons may be included in the total area. Such surrounding environment varies in all shapes for each individual site, making it unfeasible to investigate every site. Previous studies, instead, assumes that 70% of the total area could be utilized for PV system installation, which called generator to system ratio or area factor [37,45,46].

In this study, data for the area factor is calculated using actual PV installation cases data, or in some cases, is assumed, depending on the land-use types. As a result of the review on the actual cases data, for the industrial complex, logistics complex, residential complex and public building case, 54.5% of the total area is being utilized for a PV system on average. In parking lot and roadside land, 18.9% and 28.4 % of the individual site area is being utilized for a PV system respectively. The observed area factors are applied in this study. In the cases of the mountainous area and farmland, the data-absent cases, their area factors are assumed to be 40% and 5% respectively.

Zhang et al. (2020 solar energy potential assessment a framework

* + 1. Density factor: PV system area to PV capacity

Fig. 3 (d) shows the graphical concept of the density factor (). As a roof-top PV for three building types, single-family, multi-family and apartment complex, the density factors were assumed to be 11.7, 4.7, 4.7 (kW/m2) respectively in previous studies [47]. As a conventional ground-mounted PV, the density factor was 9.57, 13.16 (kW/m2) in previous studies [48,49]. For more efficient land-use, new types of PV technologies such as PV tree [48–50] and agroPV [51–53] would be considered as well.

In this study, the data for the density factor is calculated using the actual PV installation cases data as well. Unlike the area factor, the density factor is applied depending on the PV technology types. For the cases of roof-top and ground-mounted PV, the area of 7.23m2 and 11.50m2 is being utilized for a PV system of 1kW capacity on average respectively. The observed density factors are applied in this study.

* + 1. Capacity factor: PV capacity to PV generation

Data for capacity factor is obtained from XX, which is calculated based on the actual power market data, where XX. Capacity factor includes all types of losses

The capacity factor is applied differently depending on the city& county where the individual sites are located.

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Fig. .

PF (Apv/Agen)

Ground Cover Ratio or (Spacing factor): Elkadeem et al. (2022) : the ratio of total land requirements compared to the actual surface area of PV panels: 20%

Ouchani et al. (2021): Ground Coverage Ratio: 20%

IRENA (2014): Ground Coverage Ratio: 20%

Land Occupancy Factor (LOF) : 1.4: Yushcenko et al. (2018) : ratio of total land requirements to the surface of PV panels.

()

Vyas et al. (2022), Land Cover Ratio (LCR) : 13.16(m2/kW) : Land Coverage Ratio, which is the ratio of land area occupied by the structures (which becomes unusable for any other purpose) to the total land area available at the project site(area occupied by structure/foundation of SPV tree can be seen in graphical representation in Fig3.))

* 1. Assumption of LCOE

2020년부터 KEEI (에너지경제연구원)에서 매년 재생에너지 원별, 유형별 LCOE(발전단가)를 조사하고 있다. 설비비용, 운영유지비용, 토지비, 기타비용 등을 포함하여 발전설비에 대한 비용항목을 표준화하여 조사한다. 학습효과 모형을 활용하여 중장기 LCOE를 전망하기도 한다. 또한 전국토를 1km2 격자단위로 구분한 격자 연산 모형을 활용하여 지역별 LCOE를 분석한다. 선행연구는 본 연구의 대상지인 경기도를 42개 지역으로 구분하고 (경기도는 31개의 county로 구성되어 있으나, 6개의 county는 town별로도 분석되어 있어서 총 42개의 지역), 또 각 지역별로 ground-mounted와 roof-top PV로 나뉘어 LCOE를 분석하였다.

LCOE assumption from KEEI. Draw a graph.

* 1. Scenario

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Table. . Scenario description

|  |  |
| --- | --- |
| Scenario | Description |
| Current Setback | PV generation potential under Setback regulation |
| No Setback | PV generation potential without Setback regulation |

Coefficient >> LCR (Land Coverage Ratio)

Power-based direct land use : Martin-Chivelet (2016)

Ground Cover Ratio or (Spacing factor): Elkadeem et al. (2022) :20%: the ratio of total land requirements compared to the actual surface area of PV panels.

Ratio >> ELR이라고 명명하자. (Effective Land Ratio)

Table. . Assumption for ----

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Explored suitable sites for PV | | | Applied parameters | | | | LCOE |
| Land-use type | Area (m2) | Number of sites | PV type | Area factor  (%) | Density factor (m2/kW) | Capacity factor |
| Industrial complex | 25,293,157 | 25,128 | Roof-top PV | 54.5 | 7.23 | Applied geographically\* | Applied geographically\* |
| Logistics complex | 5,450,717 | 1,848 |
| Residential complex | 44,657,356 | 132,000 |
| Public buildings | 5,618,738 | 12,810 |
| Mountainous area |  |  | Ground-mounted PV | 5 | 11.50 | Applied geographically\* |
| Farmland |  |  | 5 |
| Parking lot |  |  | 18.9 |
| Roadside land |  |  | 28.4 |
| Water | 56,372,992 | 446 | Floating PV | 30 | 10 |

\* It is applied differently depending on the city & county where the individual site is located.

[54] Farmland 5% -> Chatzipanagi et al.(2023) Table 1

[55–57] Water 10% -> Kim et al. (2019)

FPV area factor 30% : [58]

FPV area factor 1% ~100 %

FPV density factor 10: [59,60]

1. Results
   1. Geographical potential of PV

**(FigA)** 경기도의 총 면적은 10,171km2인데, 이 중 현재 Current Setback 시나리오 하에서는 6.7% (684km2)가 태양광 설치 가능한 면적으로 나타났고, 한편 setback regulation이 사라지는 경우 설치가능 면적은 12.0% (1,218km2)로 증가 (setback regulation 대비 77.9% 증가)하는 것으로 나타났다.

**(FigB)** 2022년까지 경기도에 보급된 태양광 용량이 1.8GW [6] 인데, Current Setback 시나리오 하에서의 태양광 잠재 보급용량이 9.0GW (2022년까지 보급된 수준의 5.0배 9.0GW/1.8GW)인 것으로 나타났다. 현재 Current Setback을 유지한다면 경기도의 보급목표(9GW)를 달성할 수 있는 것으로 나타난다. 한편 setback regulation이 없어지면 태양광 잠재 보급용량은 12.4GW로, current setback regulation 대비 37.7%만큼 증가하는 것으로 나타난다.

**(FigC)** 국가 탄소중립 시나리오에서 최소한으로 필요한 태양광 발전량이 449TWh이라고 가정한 것을 상기해보면 (‘Introduction’ 부분 참고), 경기도는 setback regulation 하에서는 잠재 발전량이 10.9TWh로 국가 탄소중립에 2.4% (10.9TWh/449TWh)를 기여할 수 있고, setback regulation을 제거하는 경우 잠재 발전량이 15.0TWh로 국가 탄소중립에 3.3%(15.0TWh/449TWh)를 기여할 수 있는 것으로 나타났다.

Roof-top PV 부지 (Industrial, Logistics, Residential, Public)는 Ground-mounted PV 부지보다 설치 가능한 면적은 상대적으로 적게 나타나지만, 개별 부지 내에서 부지의 활용율이 높고 (area factor is assumed higher), 밀도 있게 설치 (density factor is assumed lower)되기 때문에, 용량과 발전량 측면에서는 상대적으로 잠재량이 많은 것으로 나타난다.

# 선행연구에서와의 비교: 경기도는 60%밖에 안남더라

장연재(2023)에서는 잔여입지면적 비중이 65% (x/1399)

본연구는 잔여 입지면적 비중이 56% (675/1208)

# Capacity 대비 Area -> 면적이 많이(혹은 적게) 필요한 부지가 많이 줄었다(혹은 늘었다.)

현재 setback regulation에서는 평균적으로 684면적에 9.0GW (76km2/GW)를 설치할 수 있는 것으로 나타났는데, setback regulation이 제거된 경우에는 1218 면적에 12.4 GW (98.2km2/GW) 설치가능한 것으로 나타났다. 태양광 설치에 필요한 면적이 늘어나는 것인데, 이는 setback regulation이 해제되었을 때, 상대적으로 태양광 설치에 부지가 많이 필요한 LandType들이 많이 포함되어 있다는 의미다.

또 setback regulation에서는 평균적으로 9.0GW의 용량으로 10.9TWh를 발전 (1.21)하는 것으로 나타나고, setback regulation이 제거된 경우에는 12.4GW의 용량으로 15.0TWh를 발전 (1.20)하는 것으로 나타났다. 설비이용률이 약간 감소하는 것인데, 이는 setback regulation이 해제되었을 때, 상대적으로 설비이용률이 낮은 지역이 조금 더 포함된다는 의미다.

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자동 생성된 설명

Fig. . PV potential by scenario in terms of area, capacity and generation

아래 Fig는 이격거리 규제가 없어졌을 때, 늘어나는 잠재발전량을 LandType별로 보여주고 있다.

**(Residential)** 경기도는 국가 전체면적의 10.2%만 차지하고 있지만, 국가 전체 인구의 27%가 살고 있는 지역이다. 그 만큼 residential 건물이 많이 있음을 의미하고, Fig에서도 확인할 수 있듯이, current setback과 no setback 시나리오 모두에서 잠재 발전량이 가장 높은 LandType인 것으로 나타났다. **경기도 가정부문의 전력소비량 제시할것(Industrial, Logistics)** RE100 달성 차원에서 Industrial과 Logistics의 잠재 발전량은 중요한 부분이다. 기업들이 RE100 달성 수단으로 비계통연계형 PPA를 선호하는 점을 고려할 때, 사업장 옥상에 바로 설치하여 자가소비를 하는 것이 유리하기 때문이다. 2022년 경기도 산업부문의 전력소비량은 74TWh 인데, 산업단지와 물류단지 옥상에서의 발전잠재량은 2.3TWh 으로 나타났다. Setback regulation이 없는 경우에는 2.8TWh (Ind: 2.3, Logistics:0.5)가 늘어, 두 LandType에서의 잠재 발전량이 2.8TWh인 것으로 나타났다. 이는 2022년 산업부문 전력소비량의 3.8%에 해당하는 전력량이다.

**(Farmland, Mountain)** Setback regulation 해제로 인해 잠재 발전량이 가장 많이 늘어나는 LandType이 Farmland와 Mountain으로 나타났다. Current setback regulation이 해제되면 Farmland의 잠재 발전량은 93.7%, Mountain의 잠재 발전량은 84.8%만큼 늘어나는 것으로 나타났다. 다만 기본적으로 Mountain과 Farmland는 horticultural에 대한 염려를 해결하는 것이 공통과제이다. (**출처필수**) Farmland는 Setback regulation 해제 뿐 아니라, AgroPV에 대한 수용성을 높이기 위해서는, 농지 소유주로 하여금 경제성 확보 from dual-function (generation and crop production on the same land)에 대한 이해도를 높여주는 것이 중요하다 (**출처필수**). Mountain의 경우도 setback regulation의 해제도 중요하지만, ‘green on green conflict’를 잘 다루는 것이 관건이다 (**출처필수**).

**(Water)** floatingPV는 Current setback 시나리오 하에서 3번째로 발전잠재량이 높은 것으로 나타났다. FPV의 density factor는 variation이 그리 크지 않다. 다만 선행연구에서는 FPV의 area factor를 최소 1%에서부터 100%까지 variation이 큰 범위에서 검토를 한다 [56–59,61]. 본 연구에서는 moderate 한 값으로 선택하여 30%로 선택하였다 [58] density factor 10으로 한거는 선행연구를 참고하였다, [59,60]. FPV는 Benefits과 costs를 구분하여 설치하는 것이 중요. [59] 논문 꼭 참고할 것

**(Public)** 공공건축물 부문은 Current setback 시나리오 하에서 발전 잠재량이 0.4TWh로, 그리 크지 않다. 공공건축물은 시청, 도청 등의 정부소유의 건물을 의미한다. 따라서 정부의 정책의지에 따라 다른 부문에 비해 비교적 태양광 도입을 다른 방해요인 (예 주민 수용성) 없이 추진가능하다는 이점이 있다.

(Roadside) 고속도로 IC/JC 근처에서 어떤 용도로도 활용되고 있지 않은 땅들을 의미한다. Water부문을 제외한 나머지 8개 부문 중에서 유일하게, 현재 토지 이용이 어떤 용도로도 활용되고 있지 않은 곳이라는 점과 도로 주변의 토지이기 때문에 보통 도로공사 소유이므로 정부기관들 간의 협조만 이루어진다면 Public부문과 함께 태양광 도입 추진에 큰 어려움이 없는 지역일 수 있다.

**(Parking)** 주차장 부문은 ground-mounted PV 부문 중에 Farmland와 함께 기존의 토지 이용목적을 여전히 달성하면서 동시에 태양광을 설치할 수 있다는 장점이 있는 곳이다.

텍스트, 스크린샷, 도표, 직사각형이(가) 표시된 사진

자동 생성된 설명

Fig. . PV generation potential by land use type

이격거리에 따른 발전 잠재량의 변화를 cities 별로(Fig. 6), spatial distribution (Fig. 7)별로도 살펴볼 필요가 있다. 국내에서는 지역별 전력자급률을 근거로 regional differential electricity pricing system 도입이 논의되고 있다. 전력가격의 지역별 차별화가 city별로 이루어진다면, 각 city들은 본인 city의 전력 소매가격을 낮추고자, 전력자급률을 높이려는 유인이 생긴다. 전력자급률을 높이기 위해서는 전력수요를 줄이거나 혹은 전력공급을 늘려야 한다. 이때, 탄소중립 전략의 일환으로서 전력수요는 높아 (전력화) 질것으로 예상한다면 전력수요는 더 이상 낮아지기 힘들다. 따라서 각 시도별로 재생에너지 도입에 적극적일 수밖에 없다.

Fig. 6에는 경기도 31개 시군의 발전 잠재량이 제시 되어 있다. 파주시의 경우 다른 city에 비해 setback regulation을 약하게 규제하고 있지만,

# 확인해봐야 할 것.

1. LandUseType별로 생기는 추가 발전 잠재량이 시군별로 다른가? Moutain의 추가잠재량은 가평군에 몰려 있다던지 >> Logistics가 이천에 50%, 안성에 31%

경기도에서 산업단지 RE100을 하겟다고 하면 이천의 이격거리 검토를 요청해봐야 하는 것이 마땅.

2.

이격거리가 있는 시군의 경우, 50% 이상이 사라지는게 대부분이다.

정책당국이 모든 잠재량이 실제로 사라지는 건지 살펴볼 필요가 있다.

같은 말이긴 하지만 몇몇 시군의 결과에 대해서는 아래와 같이 해석하는 것이 의미가 있을 수 있다. Current setback과 No setback, 두가지 시나리오를 해석함에 있어서 Current setback에서 규제가 풀림으로 인해 No setback으로 잠재량이 증가한다고 해석할 수 있는 한편, No setback에서 setback이 생김으로 인해 줄어든 potential으로도 해석이 가능하다. 후자와 같은 해석은

지역별 탄소중립 측면에서 접근을 해볼까? 시군별 온실가스 인벤토리 (전력공급부문)를 살펴보고 이야기를 만들어보자.

# 수원시는 Setback 규제가 적용되는 지역임에도 불구하고, Setback규제 해제로 인한 추가 잠재량이 없다. 반면 포천, 과천, 여주, 동두천, 양평, 이천, 가평 지역은 대부분의 potential이 사라졌음. Geographical 하게 살펴보면 다음의 그림과 같음 (GIS그림)

텍스트, 스크린샷, 도표, 그래프이(가) 표시된 사진

자동 생성된 설명

Fig. . PV generation potential by cities In which ‘current setback’시나리오의 경우에는 ‘Land Use Type’을 모두 합쳐서 하나의 색으로 표시되어 있고, ‘No setback’ 시나리오로 인해 추가되는 발전 잠재량은 각 Land Use Type별로 색으로 표시해 놓았다. Bar chart는 ‘Current Setback’ 시나리오 기준으로 발전 잠재량이 큰 순서대로 왼편부터 나열해놓았다.

텍스트, 지도, 폰트, 그래픽 디자인이(가) 표시된 사진

자동 생성된 설명

Fig. . Spatial distribution of PV generation potential

* 1. Supply curve of PV

Average LCOE of ground-mounted PV는 규모별로 최소 123.4Won/kWh (20MW 용량급), 최대 152.0Won/kWh (100kW 용량) 인것으로 나타났다 [62]. 규모별로 LCOE에 차이가 있는 것은 규모의 경제가 발생하는 것으로부터 비롯한다. 한편 LCOE는 지역별 편차가 더 크게 나타나는데, 이는 지리적요인 (일사량), 규제요인 (개발불가지역), 경제적요인 (지가)의 차이로부터 비롯한다. 경기 지역에서 최소 LCOE는 연천군 지역으로, ground-mounted PV의 경우 146Won/kWh, roof-top PV의 경우 129Won/kWh으로 나타났다. 한편 최대 LCOE는 안양시 동안구로, ground-mounted PV의 경우 1,140Won/kWh, roof-top PV의 경우 1,121Won/kWh 인 것으로 나타났다 (**SupplementaryMaterial**). 앞 절(3.1절)에서 분석한 개별부지별 태양광 적지에 지역별 유형별 LCOE를 적용하면 아래 Fig. 8와 같이 geospatial supply curve를 도출해낼 수 있다. Setback 규제가 사라졌을 때 공급곡선이 하향이동하는 것을 살펴볼 수 있으며, 이는 i) 온실가스 감축, ii) 경제적 비용, iii) 경제적 잠재량 측면에 영향을 준다 as followings.

온실가스 감축 측면에서 태양광 발전은 avoided emissions 효과를 갖고 있다. 다시 말해, 이격거리 규제로 인해 설치할 수 없는 태양광 발전량 만큼 다른 에너지원을 통해 발전을 해야 하므로 온실가스 감축기회를 상실하게 된다. [63] 이격거리 규제로 인해 연간 4.1TWh의 잠재량이 줄어드는데, 이를 전력배출계수 (0.4434 tCO2/MWh)를 적용하여 온실가스 배출량으로 환산하면 1.82MtCO2 이다. 이는 2021년 국가 전체 배출량(676.65 MtCO2)의 0.27%, 경기도 배출량(87.74 MtCO2)의 2.1%이다.

경기도의 태양광 보급목표인 9GW는 연간 10.72TWh 발전량과 상응하며, 이를 Fig. 8에 표시해 놓았다 (dashed vertical line). 보급목표를 달성하기 위해 사회 전체적으로 소요되는 최소한의 비용을 발전량과 LCOE의 곱 (dashed vertical line 기준 왼편에 위치한 bar chart 면적들의 합)으로 간주할 수 있다**(출처?)**. 이 때 Current setback 시나리오의 경우, 2,809 Million USD의 비용이 소요되고, No setback 시나리오의 경우, 1,609 Milion USD의 비용이 소요되는 것으로 나타났다. 같은 양(10.72TWh)의 태양광 발전량을 공급하는데, 이격거리 규제를 해제하는 경우, 현재 대비 42.7%의 비용 절감을 할 수 있는 것으로 나타났다. **경제학 원론적인 이야기**

2023년 SMP가격은 167.0원/kWh이었으며, 이를 Fig. 8에 표시해 놓았다 (dashed horizontal line). 개별부지의 LCOE가 SMP보다 낮을 때 경제성이 확보되는 것으로 간주할 수 있다 (시장잠재량) **(출처?)**. Current Setback 시나리오의 경우 시장잠재량이 1.55TWh 인 것으로 나타나고, No Setback 시나리오의 시장잠재량은 4.04TWh으로 나타난다. 시장 잠재량을 앞서 살펴본 기술 잠재량과 함께 Table. 4에 정리해놓았으며, 이를 토대로 다음의 세가지 의미를 도출할 수 있다. i) 이격거리 규제가 사라지는 경우, 시장잠재량은 현재보다 160% 만큼 증가하는 것으로 나타난다. ii) 이는 이격거리 규제가 기술 잠재량에 미치는 영향 (27.3% 증가) 에 비해 그 증가율이 크다. 이는 이격거리 규제가 단순히 물리적 공간의 제한을 넘어서, 경제적 타당성의 제약으로 더 크게 작용하고 있음을 의미한다. iii) 나아가 이격거리 규제 유/무에 따라 태양광 도입의 기술적 가능성이 경제적 타당성으로 전환될 가능성을 살펴보는 것이 필요하다. 이를 살펴보기 위해 시나리오별 기술적 잠재량 대비 시장 잠재량의 비중을 살펴보면, Current setback 시나리오에서는 기술적 잠재량에서 경제성이 확보된 비중이 14.2%인데 반해, No setback 시나리오에서는 그 비중이 26.9%로 증가한다. 이는 규제 완화가 태양광 도입의 기술적 가능성을 경제적 타당성으로 전환될 확률을 높임을 의미한다.

Table. . Summary of results

|  |  |  |  |
| --- | --- | --- | --- |
|  | Economic  (A) | Technical  (B) | Share  (A/B) |
| Current SB  (C) | 1.55 | 10.9 | 14.2% |
| No SB  (D) | 4.04 | 15.0 | 26.9% |
| IncreaseRate  (D-C/C) | 160.6% | 27.3% | - |

이격거리가 시장잠재량에 미치는 영향은

Supplycurve 선행연구: [64–68]

텍스트, 스크린샷, 도표, 그래프이(가) 표시된 사진

자동 생성된 설명

Fig. . Geospatial supply curve of PV generation.

* 1. CO2 mitigation potential of PV

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1. Conclusions

Electrification

2022년 기준으로 경기도는 국가 전체 태양광 발전량의 6.9%만큼 기여하고 있음을 감안할 때, 국가 탄소중립에 경기도가 기여할 수 있는 부분이 줄어드는 것으로 나타난다. 다만 다음의 세가지를 생각해보아야 한다. 첫째는 다른 지역의 태양광 발전 잠재량이 얼마가 되는지 확인이 필요하다. 둘째는 탄소중립 시나리오는 GIS를 통한 공간정보 분석을 바탕으로 하지 않고, 탄소중립에 따른 에너지 믹스를 중점으로 살펴본 결과이므로, 본 연구와 방법론에 있어 다소 차이가 있다. 셋째는 탄소중립 시나리오에서 재생에너지가 차지하는 비중이 너무 큰 건 아닌지 살펴보아야 한다.

면적 측면에서는 groundmounted 유형의 부지들이 많기 때문에, Area factor와 density factor를 높이는 일이 경기도에는 특히 중요한 일이다.

**CRediT authorship contribution statement**

**Seungho Jeon:** ABC. **Gildong Hong:** ABC. **Gyeonggi Do:** AB

**Declaration of competing interest**

The authors declare that they have no know competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] Crippa M, Guizzardi M, Pagani F, Banja M, Muntean M, Schaaf E, et al. GHG emissions of all world countries. European Union; 2023. https://doi.org/10.2760/235266.

[2] The Government of the Republic of Korea. The Republic of Korea’s enhanced update of its first NDC. 2021.

[3] The Government of the Republic of Korea. 2050 carbon neutral strategy of the Republic of Korea. 2020.

[4] IRENA. Renewable energy statistics 2023. International Renewable Energy Agency; 2023.

[5] The Government of the Republic of Korea. The 10th basic plan for electricity supply and demand. 2023.

[6] KEA. New & Renewable Energy Statistics 2022. 2023.

[7] KEA. New&renewable energy white paper. 2020.

[8] Papież M, Śmiech S, Frodyma K. Determinants of renewable energy development in the EU countries. A 20-year perspective. Renewable and Sustainable Energy Reviews 2018;91:918–34. https://doi.org/10.1016/j.rser.2018.04.075.

[9] Abdmouleh Z, Alammari RAM, Gastli A. Review of policies encouraging renewable energy integration & best practices. Renewable and Sustainable Energy Reviews 2015;45:249–62. https://doi.org/10.1016/j.rser.2015.01.035.

[10] Thapar S, Sharma S, Verma A. Economic and environmental effectiveness of renewable energy policy instruments: Best practices from India. Renewable and Sustainable Energy Reviews 2016;66:487–98. https://doi.org/10.1016/j.rser.2016.08.025.

[11] Vasconcelos RM de, Silva LLC, González MOA, Santiso AM, de Melo DC. Environmental licensing for offshore wind farms: Guidelines and policy implications for new markets. Energy Policy 2022;171. https://doi.org/10.1016/j.enpol.2022.113248.

[12] Salvador S, Gimeno L, Sanz Larruga FJ. The influence of maritime spatial planning on the development of marine renewable energies in Portugal and Spain: Legal challenges and opportunities. Energy Policy 2019;128:316–28. https://doi.org/10.1016/j.enpol.2018.12.066.

[13] deCastro M, Salvador S, Gómez-Gesteira M, Costoya X, Carvalho D, Sanz-Larruga FJ, et al. Europe, China and the United States: Three different approaches to the development of offshore wind energy. Renewable and Sustainable Energy Reviews 2019;109:55–70. https://doi.org/10.1016/j.rser.2019.04.025.

[14] Hoffmann AS, Carvalho GH de, Cardoso RAF. Environmental licensing challenges for the implementation of photovoltaic solar energy projects in Brazil. Energy Policy 2019;132:1143–54. https://doi.org/10.1016/j.enpol.2019.07.002.

[15] Snyder B, Kaiser MJ. Offshore wind power in the US: Regulatory issues and models for regulation. Energy Policy 2009;37:4442–53. https://doi.org/10.1016/j.enpol.2009.05.064.

[16] Ko I. Rural opposition to landscape change from solar energy: Explaining the diffusion of setback restrictions on solar farms across South Korean counties. Energy Res Soc Sci 2023;99. https://doi.org/10.1016/j.erss.2023.103073.

[17] Sun H, Heng CK, Reindl T, Lau SSY. Visual impact assessment of coloured Building-integrated photovoltaics on retrofitted building facades using saliency mapping. Solar Energy 2021;228:643–58. https://doi.org/10.1016/j.solener.2021.09.087.

[18] Chiabrando R, Fabrizio E, Garnero G. On the applicability of the visual impact assessment OAISPP tool to photovoltaic plants. Renewable and Sustainable Energy Reviews 2011;15:845–50. https://doi.org/10.1016/j.rser.2010.09.030.

[19] Tsoutsos T, Frantzeskaki N, Gekas V. Environmental impacts from the solar energy technologies. Energy Policy 2005;33:289–96. https://doi.org/10.1016/S0301-4215(03)00241-6.

[20] Wüstenhagen R, Wolsink M, Bürer MJ. Social acceptance of renewable energy innovation: An introduction to the concept. Energy Policy 2007;35:2683–91. https://doi.org/10.1016/j.enpol.2006.12.001.

[21] van den Berg K, Tempels B. The role of community benefits in community acceptance of multifunctional solar farms in the Netherlands. Land Use Policy 2022;122. https://doi.org/10.1016/j.landusepol.2022.106344.

[22] Henni S, Staudt P, Weinhardt C. A sharing economy for residential communities with PV-coupled battery storage: Benefits, pricing and participant matching. Appl Energy 2021;301. https://doi.org/10.1016/j.apenergy.2021.117351.

[23] Perger T, Wachter L, Fleischhacker A, Auer H. PV sharing in local communities: Peer-to-peer trading under consideration of the prosumers’ willingness-to-pay. Sustain Cities Soc 2021;66. https://doi.org/10.1016/j.scs.2020.102634.

[24] Fina B, Auer H, Friedl W. Profitability of PV sharing in energy communities: Use cases for different settlement patterns. Energy 2019;189. https://doi.org/10.1016/j.energy.2019.116148.

[25] Simpson G. Looking beyond incentives: the role of champions in the social acceptance of residential solar energy in regional Australian communities. Local Environ 2018;23:127–43. https://doi.org/10.1080/13549839.2017.1391187.

[26] Park E, Ohm JY. Factors influencing the public intention to use renewable energy technologies in South Korea: Effects of the fukushima nuclear accident. Energy Policy 2014;65:198–211. https://doi.org/10.1016/j.enpol.2013.10.037.

[27] Worldbank. Population density by country. Worldbank 2024. https://data.worldbank.org/indicator/EN.POP.DNST (accessed September 26, 2024).

[28] Hong S, Lee M, Kim E. Rational setback regulations: The initial step towards RE100. 2022.

[29] Chang Y, Cho I. Assessment of setback regulation policies on solar photovoltaic deployment. 2023.

[30] Kwon K, Kim Y, Jo E. Nowhere to go: How South Korea’s siting regulations are strangling solar. 2020.

[31] KOSIS. Area by province. Korean Statistical Information Service 2024. https://kosis.kr/statHtml/statHtml.do?orgId=101&tblId=DT\_1ZGA17&conn\_path=I2 (accessed September 24, 2024).

[32] KOSIS. Population by province. Korean Statistical Information Service 2024.

[33] Lee CS, Lee K-W. A study on the spatial units adequacy for the regional pricing of electricity: based on electricity self-sufficiency rates by Si ‧ Gun ‧ Gu. Journal of the Economic Geographical Society of Korea 2023. https://doi.org/10.23841/egsk.2023.26.2.96.

[34] Climate Group RE100. RE100 members. Climate Group RE100 2024.

[35] GRI. Gyeonggi of Opportunity, Vision 2030. Suwon: 2023.

[36] ICLEI. Gyeonggi-do unveils ‘Gyeonggi RE100 Vision’ for a sustainable future. International Council for Local Environmental Initiatives 2023. https://talkofthecities.iclei.org/gyeonggi-do-unveils-gyeonggi-re100-vision-for-a-sustainable-future/ (accessed September 12, 2024).

[37] Martín-Chivelet N. Photovoltaic potential and land-use estimation methodology. Energy 2016;94:233–42. https://doi.org/10.1016/j.energy.2015.10.108.

[38] Wang P, Yu P, Huang L, Zhang Y. An integrated technical, economic, and environmental framework for evaluating the rooftop photovoltaic potential of old residential buildings. J Environ Manage 2022;317. https://doi.org/10.1016/j.jenvman.2022.115296.

[39] Martín-Chivelet N. Photovoltaic potential and land-use estimation methodology. Energy 2016;94:233–42. https://doi.org/10.1016/j.energy.2015.10.108.

[40] Yang Q, Huang T, Wang S, Li J, Dai S, Wright S, et al. A GIS-based high spatial resolution assessment of large-scale PV generation potential in China. Appl Energy 2019;247:254–69. https://doi.org/10.1016/j.apenergy.2019.04.005.

[41] Bennett C, Blanchet J, Trowell K, Bergthorson J. Decarbonizing Canada’s energy supply and exports with solar PV and e-fuels. Renew Energy 2023;217. https://doi.org/10.1016/j.renene.2023.119178.

[42] Wang P, Zhang S, Pu Y, Cao S, Zhang Y. Estimation of photovoltaic power generation potential in 2020 and 2030 using land resource changes: An empirical study from China. Energy 2021;219. https://doi.org/10.1016/j.energy.2020.119611.

[43] Edalati S, Ameri M, Iranmanesh M. Comparative performance investigation of mono- and poly-crystalline silicon photovoltaic modules for use in grid-connected photovoltaic systems in dry climates. Appl Energy 2015;160:255–65. https://doi.org/10.1016/j.apenergy.2015.09.064.

[44] Mussard M, Amara M. Performance of solar photovoltaic modules under arid climatic conditions: A review. Solar Energy 2018;174:409–21. https://doi.org/10.1016/j.solener.2018.08.071.

[45] Dhunny AZ, Doorga JRS, Allam Z, Lollchund MR, Boojhawon R. Identification of optimal wind, solar and hybrid wind-solar farming sites using fuzzy logic modelling. Energy 2019;188. https://doi.org/10.1016/j.energy.2019.116056.

[46] Saraswat SK, Digalwar AK, Yadav SS, Kumar G. MCDM and GIS based modelling technique for assessment of solar and wind farm locations in India. Renew Energy 2021;169:865–84. https://doi.org/10.1016/j.renene.2021.01.056.

[47] D’Agostino D, Parker D, Melià P, Dotelli G. Optimizing photovoltaic electric generation and roof insulation in existing residential buildings. Energy Build 2022;255. https://doi.org/10.1016/j.enbuild.2021.111652.

[48] Vyas M, Chowdhury S, Verma A, Jain VK. Solar Photovoltaic Tree: Urban PV power plants to increase power to land occupancy ratio. Renew Energy 2022;190:283–93. https://doi.org/10.1016/j.renene.2022.03.129.

[49] Almadhhachi M, Seres I, Farkas I. Sunflower solar tree vs. flat PV module: A comprehensive analysis of performance, efficiency, and land savings in urban solar integration. Results in Engineering 2024;21. https://doi.org/10.1016/j.rineng.2023.101742.

[50] Ibrahim MM, Ashor K. NEW generation of solar energy: Investigation and implementation of artificial solar tree application in Egypt. Solar Energy 2024;278. https://doi.org/10.1016/j.solener.2024.112787.

[51] Anusuya K, Vijayakumar K, Leenus Jesu Martin M, Manikandan S. Agrophotovoltaics: enhancing solar land use efficiency for energy food water nexus. Renewable Energy Focus 2024;50. https://doi.org/10.1016/j.ref.2024.100600.

[52] Safat Dipta S, Schoenlaub J, Habibur Rahaman M, Uddin A. Estimating the potential for semitransparent organic solar cells in agrophotovoltaic greenhouses. Appl Energy 2022;328. https://doi.org/10.1016/j.apenergy.2022.120208.

[53] Junedi MM, Ludin NA, Hamid NH, Kathleen PR, Hasila J, Ahmad Affandi NA. Environmental and economic performance assessment of integrated conventional solar photovoltaic and agrophotovoltaic systems. Renewable and Sustainable Energy Reviews 2022;168. https://doi.org/10.1016/j.rser.2022.112799.

[54] Chatzipanagi A, Taylor N, Jaeger-Waldau. Overview of the Potential and Challenges for Agri-Photovoltaics in the European Union. Luxembourg: 2023. https://doi.org/10.2760/208702.

[55] Kim SM, Oh M, Park HD. Analysis and prioritization of the floating photovoltaic system potential for reservoirs in Korea. Applied Sciences (Switzerland) 2019;9. https://doi.org/10.3390/app9030395.

[56] Kakoulaki G, Gonzalez Sanchez R, Gracia Amillo A, Szabo S, De Felice M, Farinosi F, et al. Benefits of pairing floating solar photovoltaics with hydropower reservoirs in Europe. Renewable and Sustainable Energy Reviews 2023;171. https://doi.org/10.1016/j.rser.2022.112989.

[57] Gonzalez Sanchez R, Kougias I, Moner-Girona M, Fahl F, Jäger-Waldau A. Assessment of floating solar photovoltaics potential in existing hydropower reservoirs in Africa. Renew Energy 2021;169:687–99. https://doi.org/10.1016/j.renene.2021.01.041.

[58] Jin Y, Hu S, Ziegler AD, Gibson L, Campbell JE, Xu R, et al. Energy production and water savings from floating solar photovoltaics on global reservoirs. Nat Sustain 2023;6:865–74. https://doi.org/10.1038/s41893-023-01089-6.

[59] Woolway RI, Zhao G, Rocha SMG, Thackeray SJ, Armstrong A. Decarbonization potential of floating solar photovoltaics on lakes worldwide. Nature Water 2024;2:566–76. https://doi.org/10.1038/s44221-024-00251-4.

[60] Almeida RM, Schmitt R, Grodsky SM, Flecker AS, Gomes CP, Zhao L, et al. Floating solar power could help fight climate change — let’s get it right. Nature 2022;606:246–9. https://doi.org/10.1038/d41586-022-01525-1.

[61] López M, Soto F, Hernández ZA. Assessment of the potential of floating solar photovoltaic panels in bodies of water in mainland Spain. J Clean Prod 2022;340. https://doi.org/10.1016/j.jclepro.2022.130752.

[62] Lim D, Lee G. Establishment and Operation of Long-Term LCOE Forecast System for Expansion of Renewable Energy(2/5). n.d.

[63] Greenhouse Gas Inventory and Research Center of Korea. Approved National Greenhouse Gas Emission and Absorption Factors. Cheongju: 2021.

[64] Wang T, Wang Y, Wang K, Fu S, Ding L. Five-dimensional assessment of China’s centralized and distributed photovoltaic potential: From solar irradiation to CO2 mitigation. Appl Energy 2024;356. https://doi.org/10.1016/j.apenergy.2023.122326.

[65] Denholm P, Margolis R. Supply Curves for Rooftop Solar PV-Generated Electricity for the Supply Curves for Rooftop Solar PV-Generated Electricity for the United States United States. 2008.

[66] Sun Y wei, Hof A, Wang R, Liu J, Lin Y jie, Yang D wei. GIS-based approach for potential analysis of solar PV generation at the regional scale: A case study of Fujian Province. Energy Policy 2013;58:248–59. https://doi.org/10.1016/j.enpol.2013.03.002.

[67] Mattsson N, Verendel V, Hedenus F, Reichenberg L. An autopilot for energy models – Automatic generation of renewable supply curves, hourly capacity factors and hourly synthetic electricity demand for arbitrary world regions. Energy Strategy Reviews 2021;33. https://doi.org/10.1016/j.esr.2020.100606.

[68] Maclaurin G, Grue N, Lopez A, Heimiller D, Rossol M, Buster G, et al. The Renewable Energy Potential (reV) Model: A Geospatial Platform for Technical Potential and Supply Curve Modeling. 2021.

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2. Definition of PR depends on researchers. [↑](#footnote-ref-3)